



Next Generation Natural Gas Vehicle Activity

U.S. Department of Energy Next Generation Natural Gas Vehicle (NGNGV) Activity

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NG Engine Technologies

Next Generation Natural Gas Vehicle Activity

Technology	Description
High Pressure Direct Injection (HPDI)	~16:1 c/r, unthrottled, high-pressure direct-injected NG (~92%) and diesel pilot (~8%), turbocharged, lean-burn (air/fuel ratio equivalent w/diesel ~100:1)
Dual-Fuel	~16:1 c/r, unthrottled, port-injected NG (~90%), direct-injected diesel pilot (~10%), turbocharged, lean-burn (air/fuel ratio ~34:1)
Spark Ignited Natural Gas (SING)—Lean Burn	~10:1 c/r, throttled, throttle body injected or port fuel injected NG, turbocharged, lean-burn (air/fuel ratio ~26:1) with closed-loop technology
Spark Ignited Natural Gas (SING)—Stoichiometric	~10:1 c/r, throttled, throttle body injected or port fuel injected NG, stoichiometric air/fuel ratio, closed-loop, enables three-way catalyst Add EGR: increase c/r ~ 12:1, increase efficiency and reduce NO _x



NGNGV Background

Next Generation Natural Gas Vehicle Activity

- U.S. DOE supports NGV R&D
 - Reduce dependence on imported petroleum
 - Reduce emissions of regulated pollutants
- NGNGV Program
 - Class 3-6 CNG prototype vehicle
 - Class 7-8 LNG prototype vehicle
 - Capable of meeting proposed 2007 emission standards (0.5 NO_x, 0.14 NMHC & 0.01 PM)
 - Competitive with diesel
 - Performance
 - Economics



NGNGV Background

Next Generation Natural Gas Vehicle Activity

NGNGV Workshop

- Original Equipment Manufacturers
- Fleet Operators
- Industry/Trade Associations
- Funding Partners
- Utilities and Fuel Distributors
- Equipment Suppliers
- National Laboratories and Research Groups
- Industry Research Groups, Consultants and University Groups



NGNGV Background

Next Generation Natural Gas Vehicle Activity

Workshop Results (for engines & vehicles)

- Engine R&D to meet 2007 emission standards
 - Lean-burn
 - Stoichiometric
 - Exhaust After-treatment
- Market Research: Identify & define best applications
 - Chassis OEM
- Near-Term Engine/Vehicle needs exist right now!



NGNGV Background

Next Generation Natural Gas Vehicle Activity

Big Picture

- Resource constraints
 - Timing
 - Funding
- 2007 proposed standards modified to 0.2 NO_x
 - Working group split on 0.5 vs. 0.2 NO_x target
- Desire to capture OEM interest
 - Engine OEM focus on (2002.5) D2 needs
 - Supplier focus- same as OEM



NGNGV Background

Next Generation Natural Gas Vehicle Activity

Phased Approach

- Phase I: Proof of Concept

Class 3-6	0.5 NO _x	0.2 NO _x
Class 7-8	0.5 NO _x	0.2 NO _x

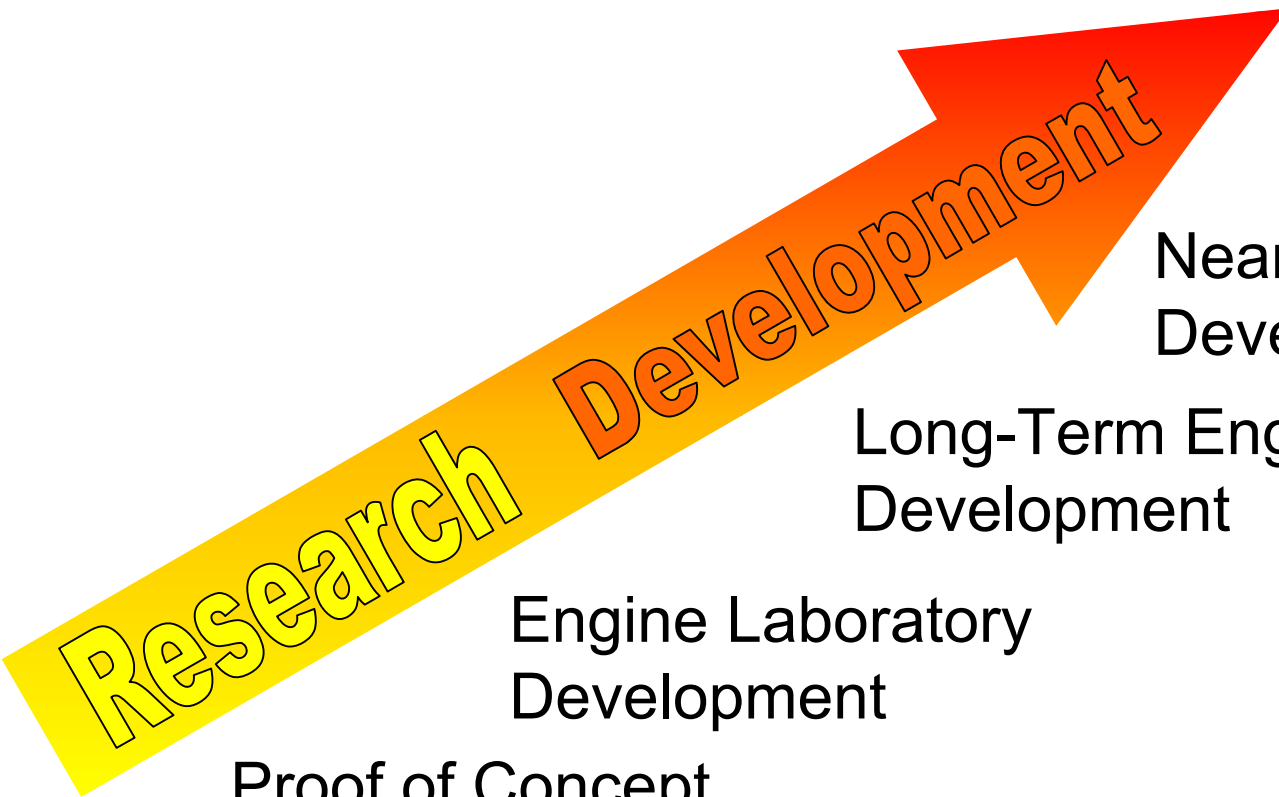
- Laboratory demonstration
 - Emission levels
 - Efficiency
- Short (12 month) duration
- Phase II: Follow-up/Build-on
 - Prototype engine & vehicle development
 - Prototype engine development
 - Near-term engine/vehicle development



Integrated R&D Strategy

Next Generation Natural Gas Vehicle Activity

Commercialization



Research

Development

Proof of Concept

Engine Laboratory
Development

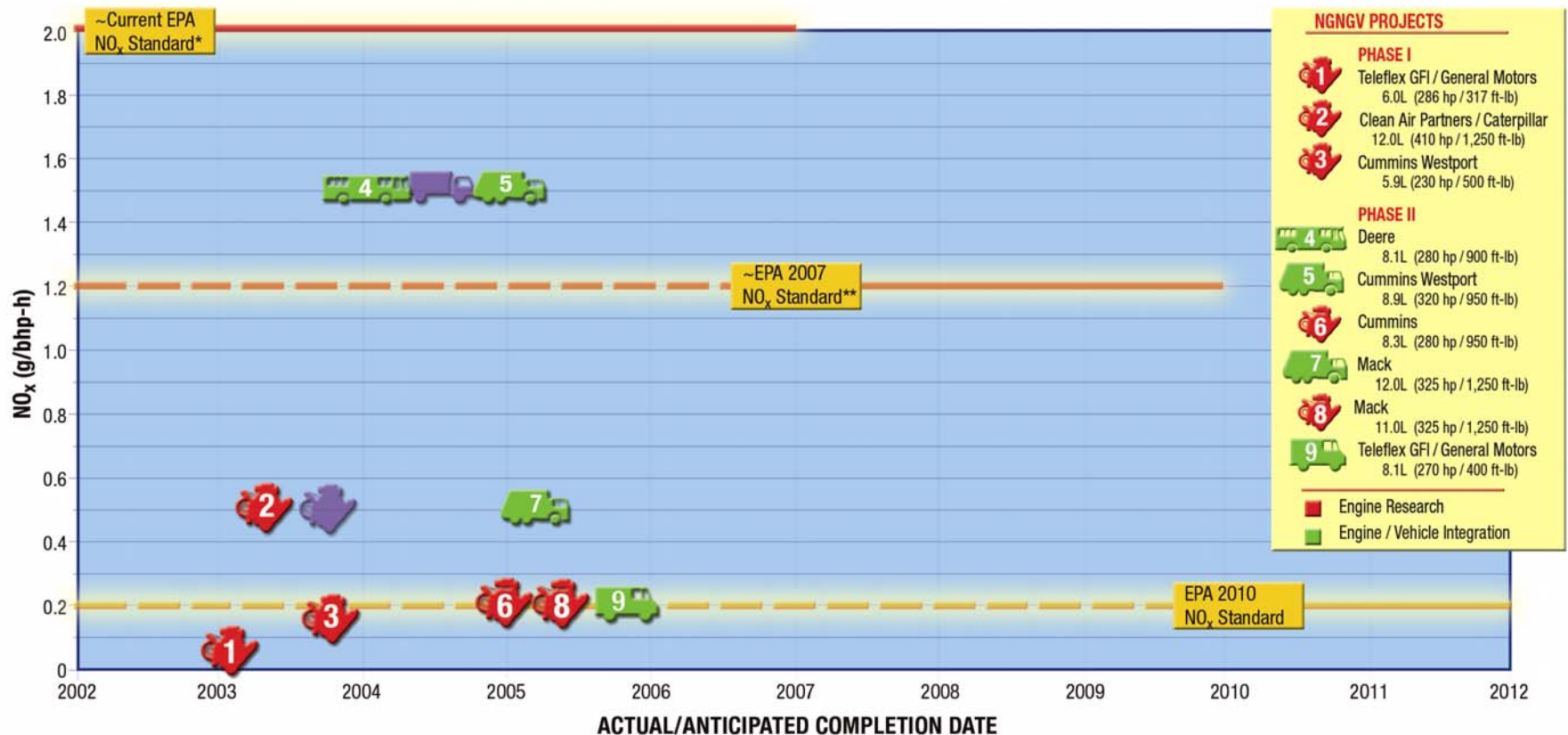
Long-Term Engine/Vehicle
Development

Near-Term Engine/Vehicle
Development



NGNGV Projects

Next Generation Natural Gas Vehicle Activity

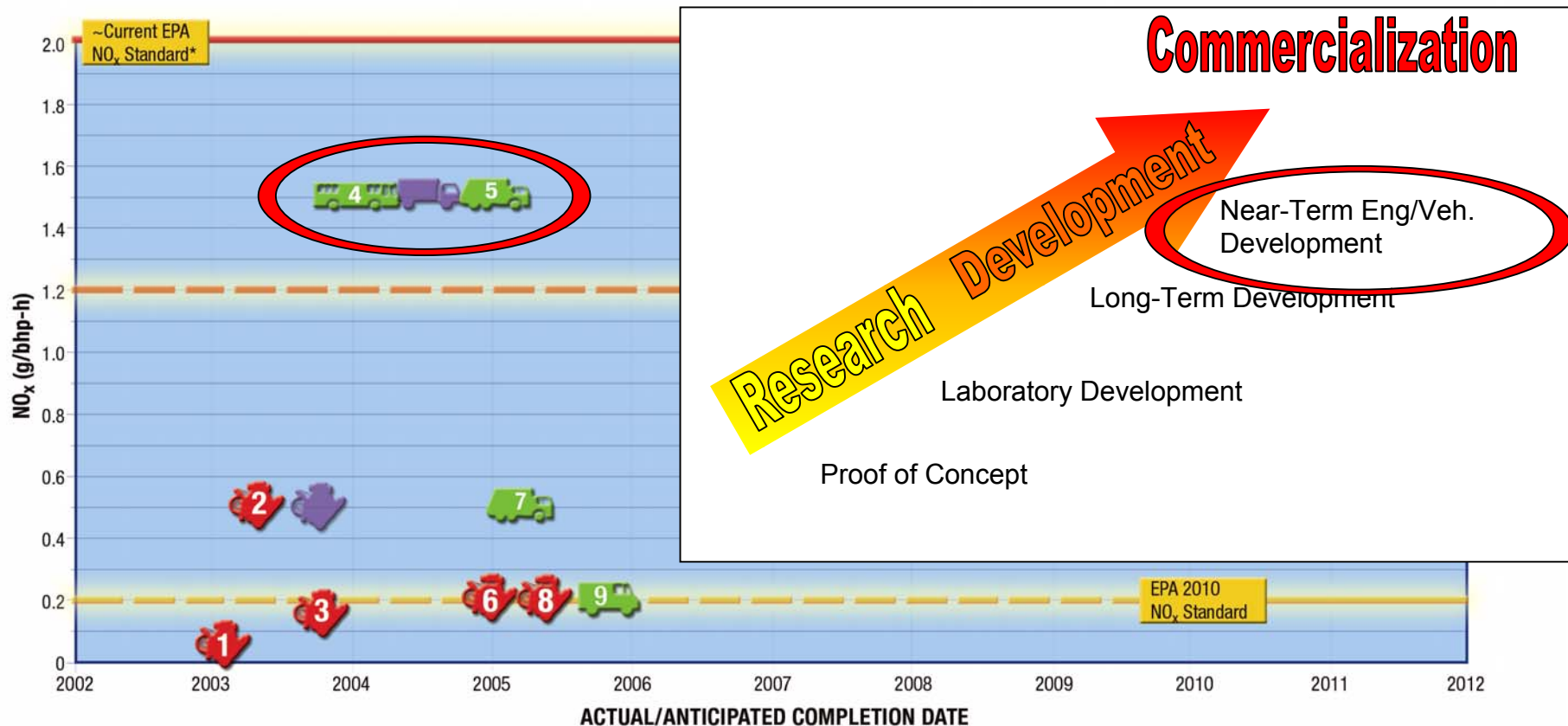




Near-Term Engine/Vehicle Development Projects



Next Generation Natural Gas Vehicle Activity





Near-Term Engine/Vehicle Development Projects



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Near-term Engine/Vehicle Development—*Combination of laboratory and on-road engine development of production-intent components and engines*

- Engine rating, emission, and vehicle application objectives
- Market-driven business case
- Chassis manufacturer desired
- Commercially viable vehicles for niche markets in 2004

Next Generation Natural Gas Vehicle Activity

Technologies

- Lean-burn SING with advanced engine controls
- LNG-capable injectors
- Optimized oxidation catalyst

Significance

Introduces HD-capable JDPS
NG 6081 to transit bus market

Ratings & Emission Targets

- 8.1L
- 250-280 hp, 735-900 ft-lb
- <1.5 g/bhp-h NO_x
- 0.05 g/bhp-h PM





Cummins-Westport, Inc.

Near-Term Engine/Vehicle Development



Next Generation Natural Gas Vehicle Activity

Technologies

- Lean-burn SING
- Advanced engine controls (Plus Technology)
- Oxidation catalyst

Significance

Increases HD NG engine offerings w/higher engine ratings, will be marketed for refuse applications

Ratings & Emission Targets

- 8.9L
- 320 hp, 1,000 ft-lb
- 1.5 g/bhp-h NO_x
- 0.05 g/bhp-h PM





Near-Term Engine/Vehicle Development



Next Generation Natural Gas Vehicle Activity

Strategy

- Market-ready, 2004 EPA- and CARB-certified NG engines
- Integrated medium-duty chassis, GVW 20,000-26,000 lb

Significance

Conventional, Type C, front-engine school bus (Argonne) and MD commercial truck (NREL) currently not available from OEM w/NG engines

Ratings & Emission Targets

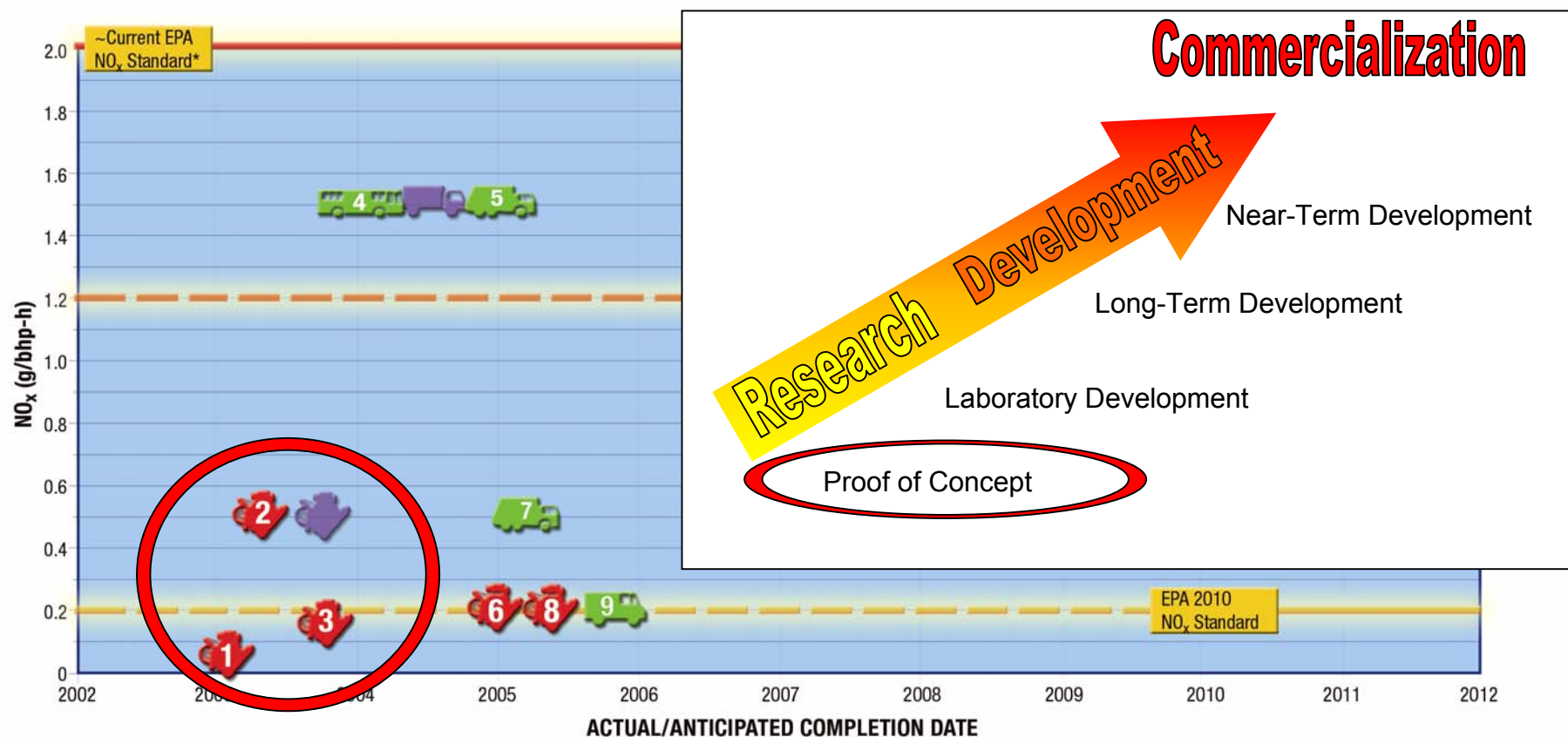
- 270-320 hp, 700-900 ft-lb
- 1.5 g/bhp-h NO_x
- 0.05 g/bhp-h PM





Proof of Concept Projects

Next Generation Natural Gas Vehicle Activity





Proof of Concept Projects

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Proof of Concept—*Laboratory demonstration of enabling technologies*

- Single or multi-cylinder test engines
- Cobbled or initial design of prototype components
- Manual controls
- Steady state operation
- Initial performance and emission assessment



Clean Air Partners Proof of Concept



Next Generation Natural Gas Vehicle Activity

Technologies

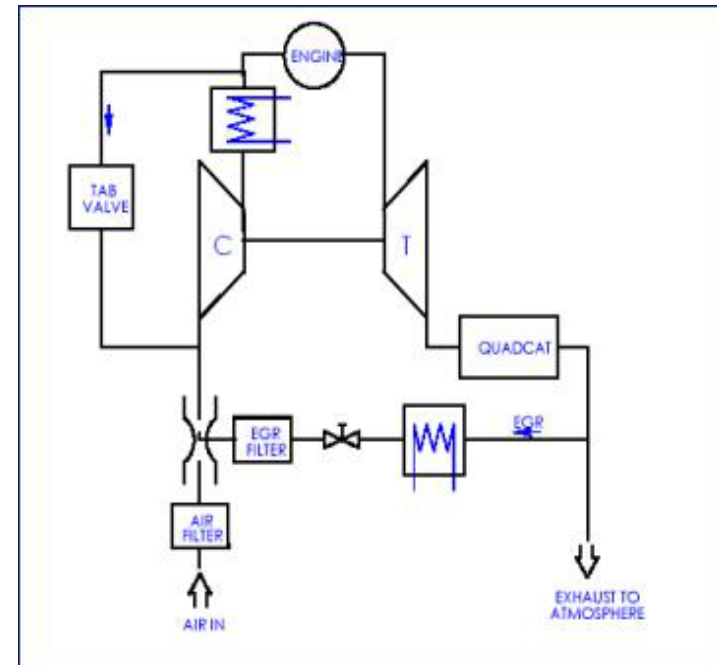
- CAP C-12 DF (12 L)
- Prototype low-pressure EGR
- CDPF

Significance

Steady state laboratory demonstration of HD lean-burn NG engine using clean exhaust to enable low-pressure EGR and very low NO_x & PM emissions

Ratings & Emission Results

- 410 hp, 1250 ft-lb,
- 0.54 NO_x , 0.0037 PM (est. ESC 13)



PROJECT COMPLETED



Cummins-Westport, Inc.

Proof of Concept



Next Generation Natural Gas Vehicle Activity

Technologies

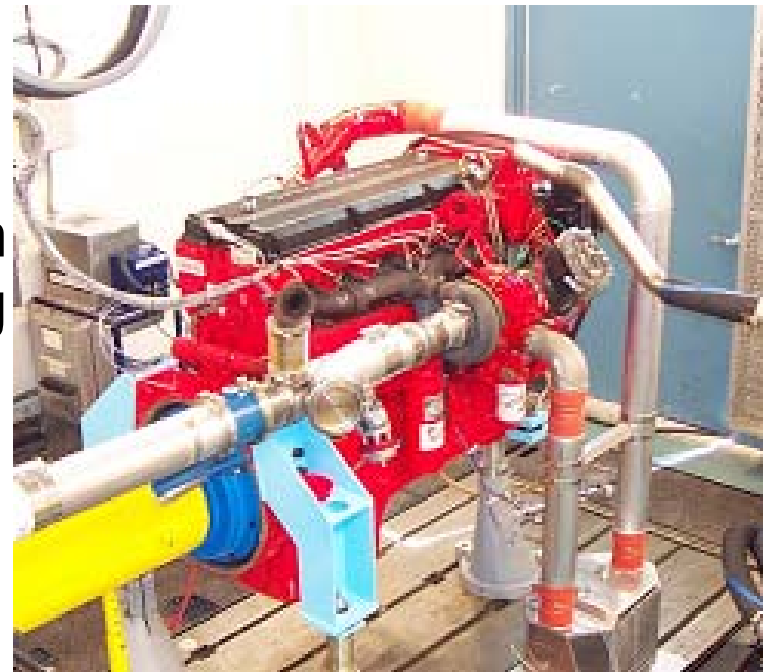
- Cummins ISX engine (15 L) & EGR
- Westport HPDI
- Oxidation catalyst

Significance

Steady state laboratory demonstration of DI, HD, lean-burn, NG engine using (mostly) production-intent hardware—achieving Class 8 ratings and low exhaust emissions

Ratings & Emission Results

- 450 hp, 1650 ft-lb
- 0.67 NO_x, 0.03 PM (AVL 8 mode)





Teleflex/GFI Control Systems Proof of Concept



Next Generation Natural Gas Vehicle Activity

Technologies

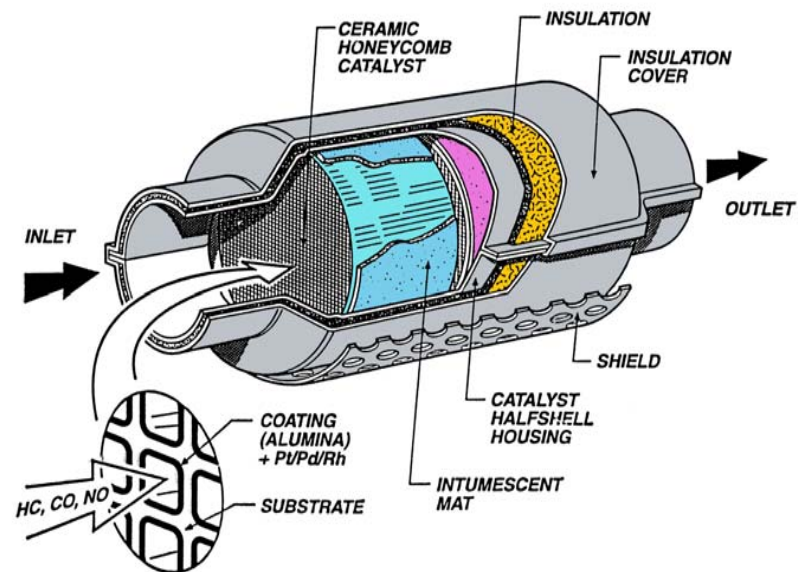
- GM's 6.0L engine
- Stoichiometric air/fuel ratio
- Optimized 3-way catalyst

Significance

Demonstrates ultra clean emission capabilities with MD market potential

Ratings & Emission Results

- 286 hp, 317 ft-lb
- 0.08 NO_x, 0.002 PM



PROJECT COMPLETED



Cummins-Westport, Inc.

Proof of Concept



Next Generation Natural Gas Vehicle Activity

Technologies

- CWI's B-Gas Plus (5.9L)
- Single bed lean-NOx adsorber

Significance

Laboratory demonstration of ultra low NOx and PM emissions and MD engine ratings with LNA technology

Ratings & Emission Results

- 230 hp, 500 ft-lb
- 0.15 NOx, 0.01 PM



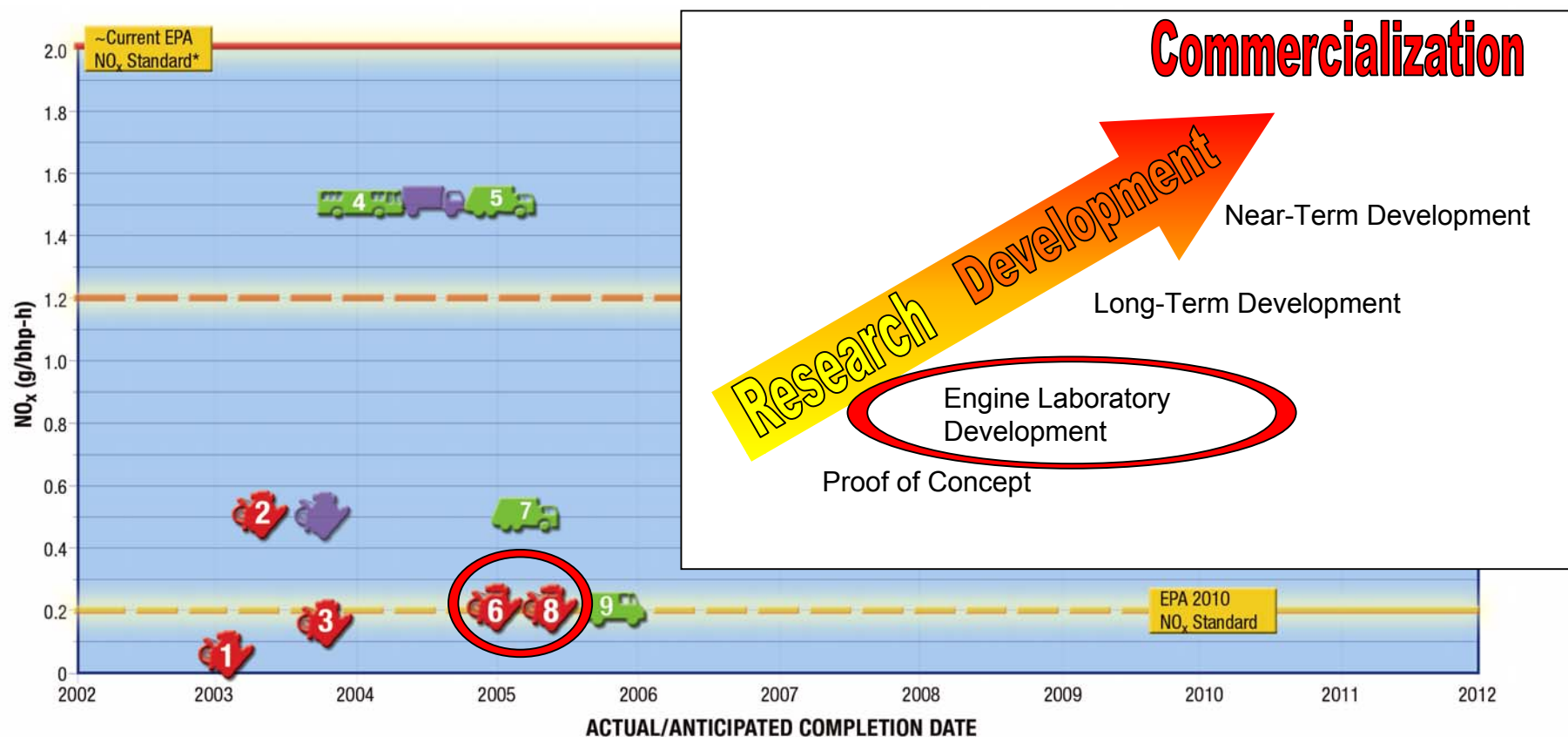
PROJECT COMPLETED



Engine Laboratory Development Projects



Next Generation Natural Gas Vehicle Activity





Engine Laboratory Development Projects



Next Generation Natural Gas Vehicle Activity

Engine Laboratory Development—*Laboratory based development of production-intent components and engines*

- Multi-cylinder engine
- Production and production-intent components
- Steady-state engine mapping
- Transient calibration development
- Durability tests
- Performance and emission assessment



Cummins Engine Laboratory Development



Next Generation Natural Gas Vehicle Activity

Technologies

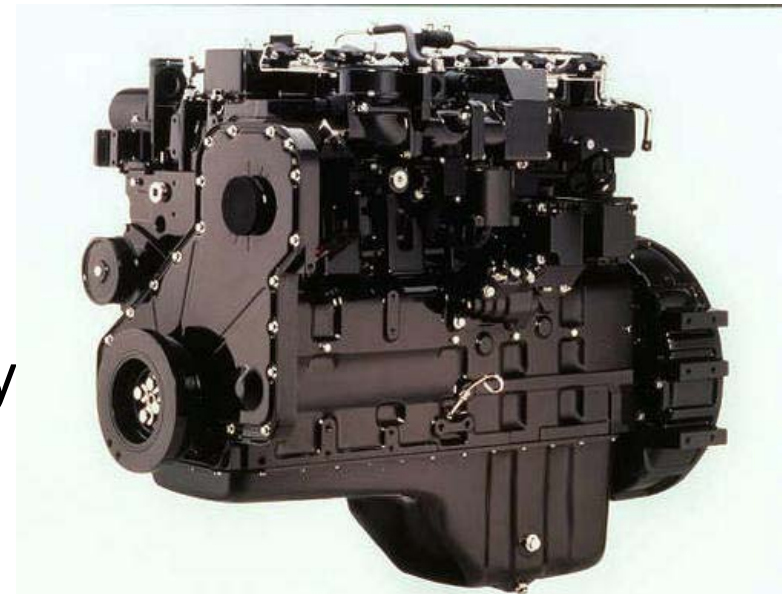
- Cummins C (8.3L) engine and EGR
- Stoichiometric air/fuel ratio
- 3-way oxidation catalyst

Significance

Potential for lower cost exhaust AT equipment, very low exhaust emissions, and med- to (light) heavy duty application capability

Ratings & Emission Targets

- 280 hp, 950 ft-lb
- 0.2 NO_x, 0.01 PM





Mack Trucks, Inc. Engine Laboratory Development



Next Generation Natural Gas Vehicle Activity

Technologies

- Mack's new 11L engine w/VVT and EGR
- Stoichiometric air/fuel ratio
- 3-way oxidation catalyst

Significance

Lots of potential from VVT, lower cost exhaust AT equipment, med- to heavy-duty applications and a vertically integrated manufacturer

Ratings & Emission Targets

- 325 hp, 1250 ft-lb
- 0.2 NO_x, 0.01 PM

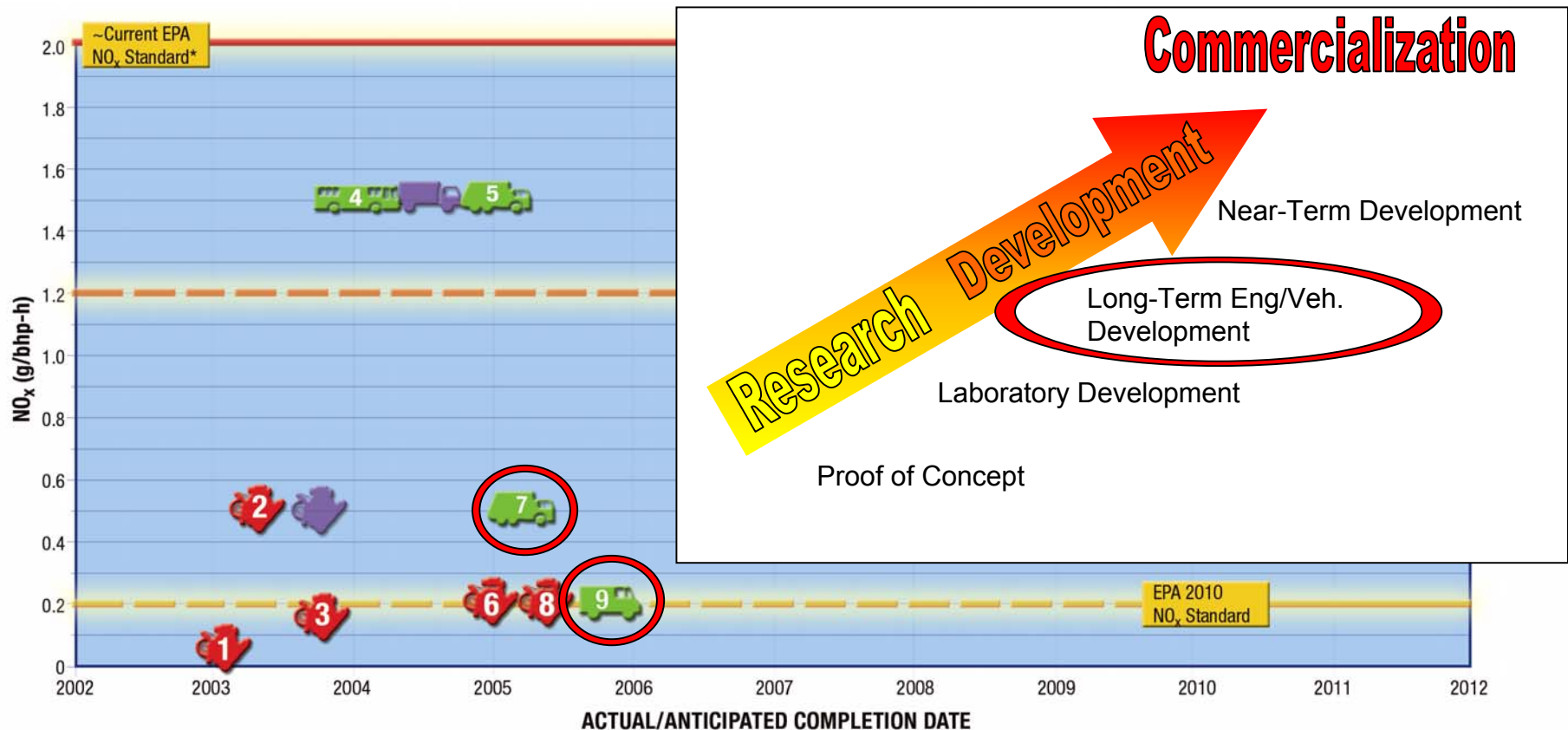




Long-Term Engine/Vehicle Development Projects



Next Generation Natural Gas Vehicle Activity





Long-Term Engine/Vehicle Development Projects



Next Generation Natural Gas Vehicle Activity

Long-term Engine/Vehicle Development—*Combination of laboratory and on-road development of gaseous fuel engines, components and after-treatment technologies*

- Engine rating, emission and vehicle application objectives
- Market driven business case
- Chassis manufacturer desired
- Commercially viable prototype vehicles for capable of 2010 emission standards in 2006-07



Mack Trucks, Inc.

Long-Term Eng/Veh. Development



Next Generation Natural Gas Vehicle Activity

Technologies

- Mack E7 (12L) engine and EGR
- Stoichiometric air/fuel ratio
- 3-way oxidation catalyst



Significance

Potential for lower cost exhaust AT equipment, med- to heavy-duty applications (refuse) and a vertically integrated manufacturer

Ratings & Emission Targets

- 325/400 hp, 1250 ft-lb,
- 0.2 NO_x, 0.01 PM



Teleflex/GFI Control Systems Long-Term Eng/Veh. Development



Next Generation Natural Gas Vehicle Activity

Technologies

- GM 8.1L engine/chassis
- Stoichiometric air/fuel ratio
- 3-way oxidation catalyst

Significance

Good market potential with low-floor shuttle bus and MD cutaway chassis with lower cost AT equipment

Ratings & Emission Targets

- 270 HP, 400 ft-lb
- 0.5 NO_x, 0.01 PM

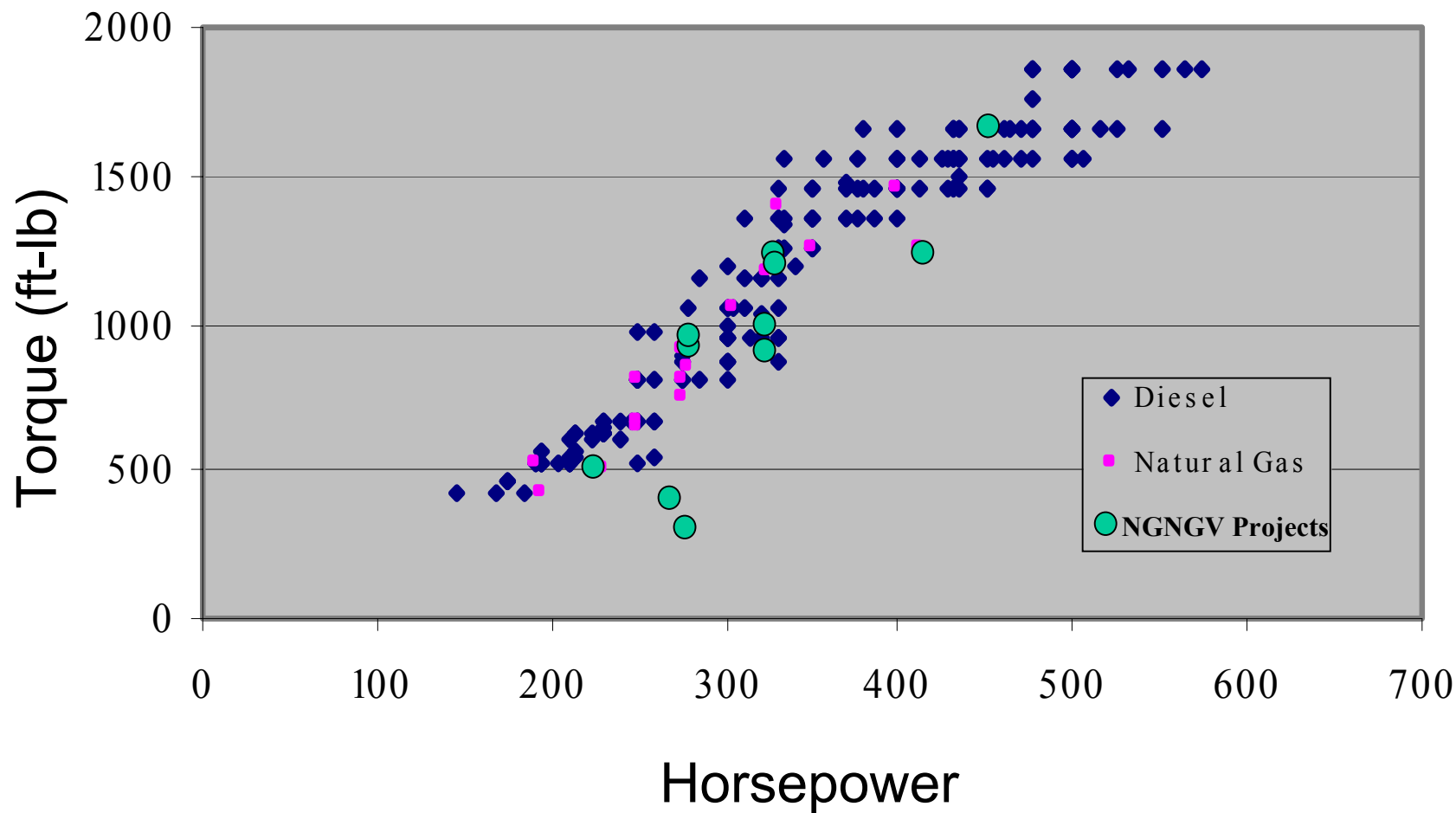




NGNGV: Room to Grow



Next Generation Natural Gas Vehicle Activity





Summary



Next Generation Natural Gas Vehicle Activity

- Phase I projects have demonstrated very low emissions with a variety of technologies in the lab
 - MD Stoich, SING; 0.08 NO_x & 0.002 PM
 - MD Lean-burn, SING; 0.15 NO_x & 0.01 PM
 - HD Lean-burn, DF; 0.5 NO_x & 0.004 PM
 - HD Lean-burn, HPDI; 0.67 NO_x & 0.03 PM
- Phase II
 - Builds on POC
 - Addresses Near-Term Need



Conclusions



Next Generation Natural Gas Vehicle Activity

- Natural gas engine development is moving forward!
- Natural gas engines can benefit from technology transfer and development
 - Exhaust Gas Recirculation
 - Lean NOx Adsorbers
 - Diesel Particulate Filters
 - Oxidation Catalysts
- Continue development of various NG engine strategies to meet program objectives



Next Generation Natural Gas Vehicle Activity

Thanks for your time and support!

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